GOLDER

TECHNICAL MEMORANDUM

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TO Michel Groleau,, Agnico Eagle Mine Limited

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WHALE TAIL MINE SITE AND DOWNSTREAM RECEIVING WATER BALANCE AND WATER QUALITY UNDER CLIMATE CHANGE SCENARIO RCP 8.5

1.0 INTRODUCTION

At the Water Licence Amendment Technical Meeting held 29-30 October 2019, Agnico Eagle made the commitment to provide results of the water quality model scenario using the Representative Concentration Pathway (RCP) 8.5 Waste Rock Storage Facility (WRSF) inputs (Commitment #3). The outcome to this commitment would provide further information for CIRNA-TRC#2, part 4, which reads:

> *"CIRNAC recommends that AEM perform water quality modelling to validate their qualitative conclusion that thaw depths penetrating through the thermal cover (as described in O'Kane 2019a and O'Kane 2019b) will not result in unacceptable water quality impacts to Mammoth Lake. The temporal scope of the modelling should be of sufficient duration to ensure it captures interflow breakthrough and subsequent stabilization of parameter concentrations."*

The RCP 8.5 climate scenario is currently the most conservative scenario available through the Intergovernmental Panel on Climate Change (IPCC; IPCC 2013), and as such, future projections using the RCP 8.5 scenario should be considered highly conservative. The current base case model (Golder 2019a, b), which represents an RCP 6.0 scenario, should be considered the appropriate scenario for informing the design of site infrastructure and the development of the monitoring program.

This technical memorandum documents the updates to the climate inputs and assumptions for the Site and Downstream Water Balance and Water Quality model based on updates to the model assumptions as well as updates that represent the RCP 8.5 climate scenario. The updates are intended to provide insight into uncertainties surrounding the effect of climate change on the water balance and water quality, specifically in relation to runoff from the Whale Tail WRSF and its effect on water quality in Mammoth Lake in post-closure.

2.0 CLIMATE CHANGE SCENARIOS

Future climate is typically projected using general circulation models (GCMs; also called global climate models) that involve the mathematical representation of global land, sea, and atmosphere interactions over a long period of time. These GCMs have been developed by various government agencies, but they share several common elements as described by IPCC (IPCC 2013). The IPCC does not run the models but acts as a clearinghouse for the distribution and sharing of the model projections.

GCMs require extensive inputs to characterize the physical processes and social development paths that could alter climate in the future. To represent the wide range of the inputs possible to global climate models, the IPCC has established a series of RCPs that help define the future levels of radiative forcing terms by plotting out the trajectory of greenhouse gas concentrations out to the year 2100. Due primarily to computational limitations in early climate modelling and the uncertainty in climate change modelling, most climate model projections extend only to the year 2100.

Beyond 2100, the radiative forcing is described using extensions of the RCPs called Extended Concentration Pathways (ECPs) that help define the trajectory of greenhouse gas concentrations out to the year 2300. It should be noted that the ECPs (i.e., climate change model projections beyond 2100) contain a high degree of uncertainty and should be considered as a conservative assessment of the impact of the climate changes on the water quality predictions. Using the ECP scenarios to project water balance and water quality past 2100 imparts this uncertainty, and consequently, a high degree of conservatism, on predictions, including those presented herein.

The four scenarios identified by the IPCC are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, named after the radiative forcing projected to occur by 2100. The RCPs and ECPs have been described more fully by van Vuuren et al (2011) in their paper, *"The representative concentration pathways: an overview",* and have been summarized in Table 1 and Figure 1. It is important to note that the RCPs in Table 1 are not derived from each other, meaning differences between the RCPs cannot be directly interpreted as a result of differences between climate policies or socio-economic developments, but may be derived from a number of sources over their development. Meinshausen et al. (2011) extends four RCP scenarios (RCP 2.6, 4.5, 6.0 and 8.5) until 2300 in support of AR5 using Earth Models of Intermediate Complexity (EMICs). The results of the EMIC extensions are consistent until 2300 with atmospheric-ocean general circulation models (AOGCM) used in AR5. Zickfield et al. (2013) use the extensions to estimate temperature changes up until the year 3000, assuming that the CO_2 concentration and forcing are held constant at year 2300 levels for all four RCP scenarios.

Table 1: Characterization of Representative Concentration Pathways

Name	Radiative Forcing in 2100 and 2300	Characterization
RCP 8.5, ECP 8.5	8.5 W/m² (2100) 12 W/m² (2300)	Increasing greenhouse gas emissions over time, with no stabilization, representative of scenarios leading to high greenhouse gas concentration levels. This scenario can be described as the high emission scenario, with a high greenhouse gas emissions baseline, no mitigation and medium to high air pollution. Past 2100, greenhouse gas emissions stabilize near 2250 at 12 W/m².
RCP 6.0, ECP 6.0	6.0 W/m²	Total radiative forcing is stabilised shortly after 2100. No additional efforts to constrain emissions from the baseline scenarios are made. This scenario can be described as the medium baseline or high mitigation case with medium baseline greenhouse gas emissions and high mitigation on the greenhouse gas emissions, with medium air pollution. Past 2100, greenhouse gas emissions stabilize near 2150 at 6.0 W/m².
RCP 4.5, ECP 4.5	4.5 W/m²	Total radiative forcing is stabilized shortly after 2100, without overshoot. This is achieved through a reduction in greenhouse gases over time through climate policy. This scenario can be described as the intermediate mitigation scenario where there is medium to low mitigation measures on a very low greenhouse gas baseline and medium air pollution. Past 2100, greenhouse gas emissions stabilize near 2150 at 4.5 W/m².

Name	Radiative Forcing in 2100 and 2300	Characterization
RCP 2.6, ECP 3PD	2.6 W/m²	"Peak and decline" scenario where the radiative forcing first reaches 3.1 W/m² by mid-century and returns to 2.6 W/m² by 2100. This is achieved through a substantial reduction in greenhouse gases over time through stringent climate policy. This scenario can be described as a low mitigation scenario meaning greenhouse gas emissions are very low and air pollution is medium to low. Past 2100, greenhouse gases remain constant at concentrations in 2100.

Note: Summarized from van Vuuren et al 2011
W/m^2 = watt per square metre.

Mean air temperature is a well understood variable in climate models and serves as a good comparison between the different climate scenarios to understand the impact of the different radiative forces of the RCPs. Climatedata.ca (2019) provides climate projections by location for several climate variables across an ensemble of multiple climate models. Figure 2 shows the comparison of annual mean temperature for Baker Lake, Nunavut for the period from 2005 to 2100 (projections beyond 2100 were not available from Climatedata.ca). Projections from RCP 6.0 are not available from Climatedata.ca (2019) and are therefore not provided on Figure 2 but are discussed in further detail in the Thermal Model Report (OKC 2019a). Projections from RCP 6.0 would fall between the projections from RCP 8.5 and RCP 4.5, but would be closer to RCP 4.5, following the radiative forcing shown in Figure 1. This graph highlights how the difference between the selected RCPs translates into air temperature on average. Initially, the projections follow similar trends for all RCPs until near 2040, at which point they branch out into different trajectories. The high emission scenario of RCP 8.5 translates into much higher air temperatures compared to the other scenarios, especially by 2100. Based on Figure 1, the air temperatures for Baker Lake (Figure 2) are reasonably expected to increase past 2100 following similar trajectories to the radiative forcing, leading to larger uncertainties in air temperatures under RCP 8.5 and the other scenarios by 2300 (compared to 2100). It is generally accepted that with increased temperature (through increased radiative forcing), mean global precipitation will also increase by an estimated 1-3% per degree Celsius increase in temperature (IPCC 2013). However, the distribution of precipitation will vary spatially, with increases in some regions and decreases in others.

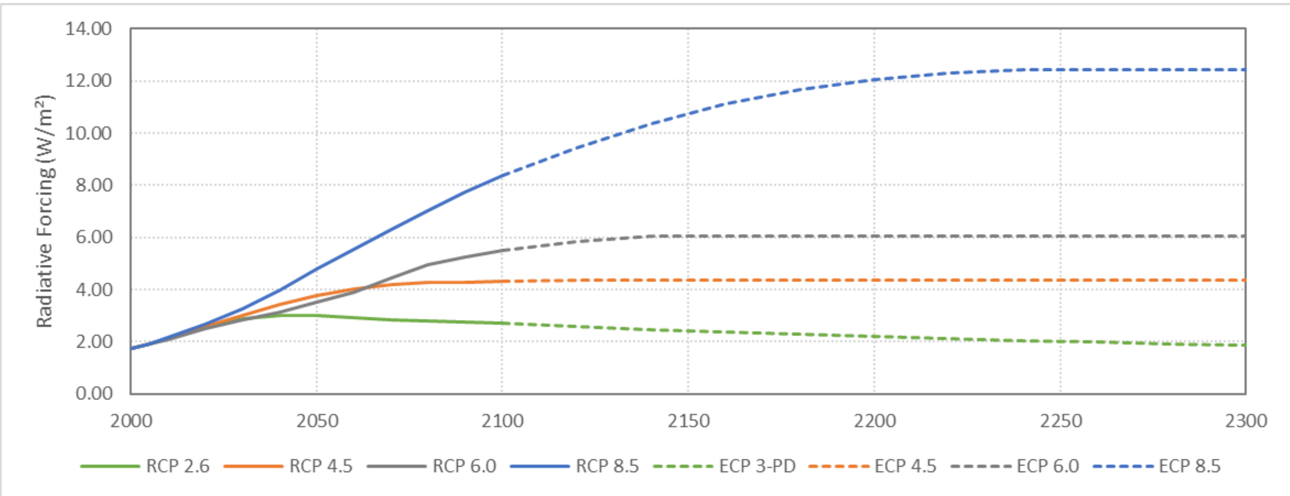

Figure 1: Radiative Forcing (W/m^2) of Representative Concentration Pathways (RCPs) and Extended Concentration Pathways (ECPs)

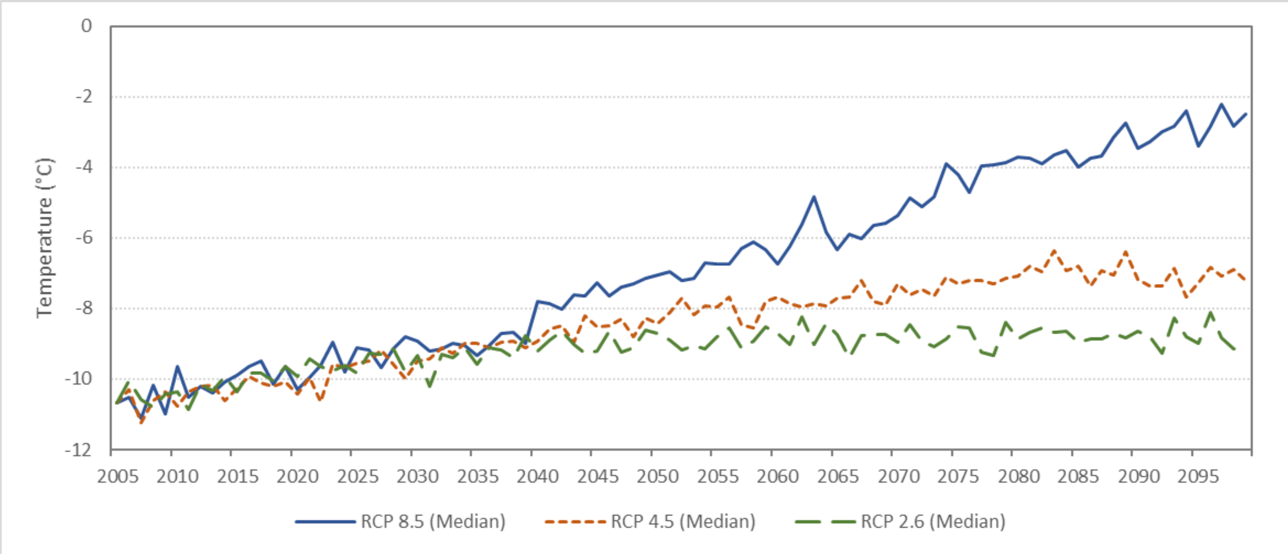

Figure 2: Comparison of Future Projected Annual Mean Temperature for Climate Model Ensemble Median for Baker Lake

Figure 2 shows the median of the climate model ensemble. It is important to note that there is additional uncertainty within the ensemble as each climate model represents the physical climate system differently. Climate projection uncertainties can lead to more conservatism and stem from three main sources (Charron 2016):

- natural variability in climate – most important for shorter timescales (decades);
- climate model structural inaccuracies – important over all timescales; and
- the future trajectories of greenhouse gases (GHG) – important over long timescales.

Representing the Earth's climate system is difficult given the sensitivity of weather phenomena to small disturbances causing natural variability. Climate model projections can vary because of differences in how they represent the earth system processes (Bush and Lemmen 2019). These differences can create biases in models and can produce slightly different results (Charron 2016). For this reason, the multi-model ensemble approach is typically used to delineate the probable range of results and will better capture the actual outcome (an inherent unknown).

To support the commitment made by Agnico Eagle to assess the effects of climate change on water balance and water quality on site and in the downstream receiving environment, this memo will focus on climate projections from RCP 8.5, as a sensitivity on the base-case scenario of RCP 6.0. The RCP 8.5 climate scenario is currently the most conservative scenario available through the IPCC, and as such, future projections using the RCP 8.5 scenario should be considered highly conservative. The current base case model (Golder 2019a and b), which represents an RCP 6.0 scenario, should be considered the appropriate scenario for informing the design of site infrastructure and the development of the monitoring program.

Moving forward, it is important to review any assessment based on climate projections. As noted above, RCP 8.5 is currently the most conservative scenario available through the IPCC; however, the IPCC are continually reviewing climate science and projections. New assessment reports are available approximately every seven years with the current assessment report treating each RCP as equally probable. Climate projections currently represent our best understanding of the future and are subject to change as new measures are put in place to mitigate increasing greenhouse gases and the climate models improve. For this reason, it is important that modelling direct measurements (e.g., climate conditions, water levels, ground temperature) of the actual future climate conditions, and how they compare to the assessed conditions (presented in Sections 4.0 and 5.0), be evaluated on a consistent basis. With the advancements made in climate change projections over time, uncertainty and conservatism in the future projections (including post-2100 projections) will likely be reduced. As well, new measures put in place to mitigate greenhouse gases may increase the probability of RCP scenarios with lower radiative forcing, helping to reduce over estimation of temperature in the currently available climate projections and validate the high level of conservatism applied to the RCP 8.5 climate scenario of the Site and Downstream Receiving Water Balance and Water Quality Model. Incorporating these advancements in climate change projections over time will provide more confidence in the future water balance and water quality projections.

Monitoring will be put in place to assess how changing air temperatures are being communicated to pore space and ground temperatures and to validate the representation of temperatures in the Site and Downstream Receiving Water Balance and Water Quality model. Monitoring will also assess pile moisture (related to possible increases in precipitation) and freeze-back distribution over time, thereby validating the predictions of the WRSF hydrology (Appendix A), as well as providing a means by which to update and improve inputs to the predictions.

By evaluating modelling analysis based on evolving climate science and monitoring site conditions in tandem, a better understanding of conservatism in the assessment and how it can be reduced is gained.

3.0 UPDATED INPUTS AND ASSUMPTIONS

Updates to the current base-case model (Golder 2019a and b), which represents an RCP 6.0 scenario, include accounting for trends in climate data, such as air temperature (Figure 3), WRSF pore space temperature, annual precipitation, and monthly evaporation. The updates also include some refinement to inputs (described below) to achieve a scenario that more closely represents the results provided by Okane (Appendix A). These refinements include accounting for runoff and interflow (both volumes and mass loads) only from areas of the WRSFs that have been shown to produce runoff and interflow, rather than being attributed to the entire footprint of the piles. The refinements also include accounting for pore space temperatures, as they are expected to be less variable than air temperature, in the calculation of mass loading from the WRSFs.

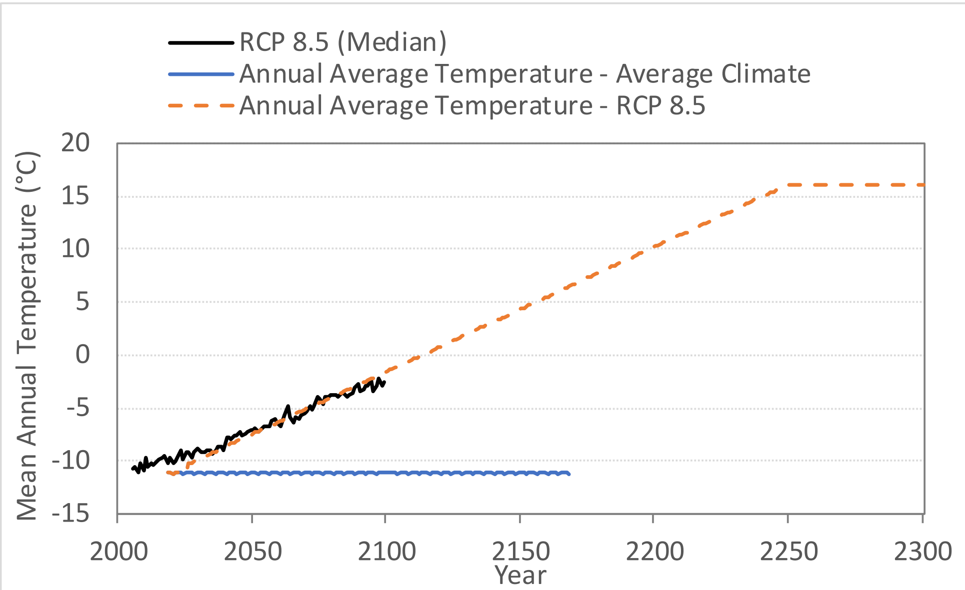

Figure 3: Modelled air temperatures for the Site and Downstream Receiving Water Balance and Water Quality Model, compared to future projected annual mean temperature for RCP 8.5 Median for Baker Lake

The updated inputs and assumptions are described in Table 2, below.

The trends derived from the RCP climate dataset result in different initial (2018) monthly temperatures and a different timing for the open water season than the historically derived average dataset previously used in the water balance. These differences are not representative of what is currently observed on site, nor are they consistent with the current water management plan for dewatering and discharge time periods. To maintain consistency with previous models through the operations period, the application of climate change trends was initiated starting in closure (January 2026). This is an acceptable assumption, as maintaining the precipitation, evaporation, and ambient air and pore space temperatures in the WRSF cover material to current average conditions until 2026 would very likely be within the uncertainty in the climate trends and current variability in the weather patterns.

The application of the RCP 8.5 climate data considered the following steps:

1. Annual precipitation based on the RCP 8.5 dataset showed an increase of 0.7 mm/yr (Appendix A). This annual increase was used to calculate annual precipitation.
2. The historical monthly precipitation distribution was applied to the annual precipitation value to calculate the amount of monthly precipitation.
3. The monthly temperature was calculated based on the applied increasing linear trend, and was used to determine whether the precipitation would accumulate as snow (sub-zero temperatures) or be applied as runoff (temperatures above 0°C).
4. Accumulated snow was released as snow melt in the first month of each year where the temperature is greater than 0°C.

Table 2: Updated inputs and assumptions for the water balance and water quality model

Input	Previous Assumption	Updated Assumption	Basis
Total Annual Precipitation	Average year, based on Baker Lake dataset from 1950 to 2015 (SNC 2015).	Average year for 2018 through 2025; increase by 0.7 mm/year thereafter. Climate change trends assumed to become level after 2250 (see RCP 8.5 in Figure 1), at which point the annual precipitation remains steady.	OKC (Appendix A)
Air Temperature	Average year, based on Baker Lake dataset from 1950 to 2015 (SNC 2015).	Average year for 2018 through 2025; increase according to linear trends by month (Table 3), developed from data provided by OKC. Climate change trends assumed to become level after 2250 (see RCP 8.5 in Figure 1), at which point the monthly average temperatures remain steady.	OKC (Appendix A)
Evaporation and Evapotranspiration	Average year, based on Baker Lake dataset from 1950 to 2015 (SNC 2015).	Average year for 2018 through 2025; increase according to linear trends by month (Table 3), developed from data provided by OKC. Climate change assumed to become level after 2250 (see RCP 8.5 in Figure 1), at which point the monthly evaporation and evapotranspiration remain steady.	OKC (Appendix A)
Distribution of annual precipitation by month	Average year, based on Baker Lake dataset from 1950 to 2015 (SNC 2015).	Linear trend analysis showed no significant trend; therefore, a constant monthly distribution of precipitation was applied to the simulation period.	OKC (Appendix A)
Volume of WRSF Runoff	Calculated using annual precipitation and based on the entire footprint of WRSF.	Calculated using annual precipitation (Table 5) and based on the footprint of the lowest bench slope.	OKC (Appendix A) Particle tracing in the landform model shows infiltration and permanent capture of water in all areas of the WRSF except for the lowest bench slope. Runoff on the benches will be captured as the benches are being back-graded.
Area from which WRSF runoff loading originates	Entire 3D footprint of WRSF (benches and slopes).	3D area of lowest bench slope.	Particle tracing in the landform model shows infiltration and permanent capture of water in all areas of the WRSF except for the lowest bench slope. Runoff on the benches will be captured as the benches are being back-graded.

Input	Previous Assumption	Updated Assumption	Basis
Effective Depth of Interaction for Runoff	30 cm	30 cm	Unchanged
Volume of WRSF Interflow	Calculated using annual precipitation and entire footprint of WRSF.	Calculated using annual precipitation (Table 5) and the footprint of the lowest slope and first bench of WRSF.	Particle tracing in the landform model shows infiltration and permanent capture of water in all areas of the WRSF except for the lowest bench slope.
Area from which WRSF interflow loading originates	Entire 3D footprint of WRSF (benches and slopes).	3D area of the lowest bench slope and first bench.	Particle tracing in the landform model shows infiltration and permanent capture of water in all areas of the WRSF except for the lowest bench slope.
Effective Depth of Interaction for Interflow through the Cover System	4.7 m	4.7 m	Unchanged
Temperature factor for runoff loadings	Based on ambient air temperature: June: 0.25 July and August: 0.5 September: 0.25	Based on air temperature (Table 3) using the Arrhenius equation. Air temperatures were calculated over time using linear equations that were fit to the data. Temperature factors were assumed to be zero (i.e., cease the release of mass loading) for all temperatures below 0°C.	Allow for adjustment as temperatures increase
Temperature factor for interflow loadings from the Cover System	Based on ambient air temperature: June: 0.25 July and August: 0.5 September: 0.25	Based on a weighted average temperatures (Table 4) of the pore spaces that are expected along the flow path of the interflow within the Cover System, using the Arrhenius equation. Pore space temperatures were calculated over time using asymptotic regressions that were fit to the data. Temperature factors were assumed to be zero (i.e., cease the release of mass loading) for all temperatures below 0°C.	Interflow volumes will interact with mass that is much cooler than air temperature, therefore slowing down oxidation and formation of reaction products.

Table 3: Climate trends for RCP 8.5, where x represents the calendar year.

Month	Air Temperature		Evaporation and Evapotranspiration		Monthly Distribution of Annual Precipitation (%)
	Increase (°C/yr)	R^2	Increase (mm/mon/yr)*	R^2	
January	0.14x -316	0.87	0.008, starting in 2140	0.0075	2.8%
February	0.13x -294	0.87	0.0066, starting in 2146	0.0067	2.5%
March	0.14x -310	0.92	0.144, starting in 2095	0.46	3.7%
April	0.17x -348	0.91	0.186, starting in 2042	0.39	5.3%
May	0.15x -308	0.93	0.145, starting in 2020	0.093	3.3%
June	0.11x -204	0.91	0.0168, starting in 2020	0.0007	13%
July	0.090x -163	0.83	-0.117, starting in 2020	0.064	16%
August	0.070x -139	0.70	-0.0945, starting in 2020	0.16	17%
September	0.080x -163	0.80	0.0047, starting in 2020	0.01	17%
October	0.10x -209	0.85	0.027, starting in 2100	0.27	9.0%
November	0.11x -253	0.89	0.096, starting in 2111	0.091	6.7%
December	0.13x -287	0.90	0	-	4.0%

* Under RCP 8.5, evaporation rates are projected to generally increase; however, some months are predicted to see less evaporation. Negative trends indicate decreasing evaporation rates

Table 4: Pore space temperature trends (°C) projected in the model.

Month	0 – 1.5 m depth			1.5 – 3 m depth			3 – 4.7 m depth			4.7 – 9 m depth		
	2018	2300	∆T (°C)	2018	2300	∆T (°C)	2018	2300	∆T (°C)	2018	2300	∆T (°C)
January	-9.8	-4.4	5.4	-9.3	-2.3	7.0	-9.5	-1.3	8.2	-8.8	-1.6	7.2
February	-11	-3.9	6.8	-10.0	-2.1	7.9	-10	-1.5	8.6	-9.9	-2.0	8.0
March	-9.2	1.3	10	-9.9	0.26	10	-11	-1.2	10	-10	-2.3	8.2
April	-8.4	9.8	18	-8.1	5.1	13	-9.7	-0.085	9.7	-9.2	-0.43	8.8
May	0.078	15	15	-4.3	8.4	13	-7.7	1.2	8.9	-10.0	-1.5	8.5
June	7.5	19	12	1.6	10	8.5	-3.4	1.8	5.2	-8.3	-0.79	7.5
July	8.3	18	10.0	4.1	11	7.0	-0.36	2.0	2.3	-4.7	-0.27	4.5
August	3.7	12	8.2	2.5	7.5	5.0	0.87	1.5	0.65	-32	-0.21	32
September	-0.89	8.0	8.9	-0.28	4.8	5.1	0.92	1.2	0.23	-2.3	-0.082	2.2
October	-3.5	1.0	4.5	-1.6	0.99	2.6	0.26	0.77	0.51	-2.1	-0.22	1.9
November	-6.1	-4.1	2.0	-3.7	-1.7	2.0	-3.1	-0.083	3.0	-3.5	-0.77	2.7
December	-9.6	-5.3	4.3	-6.9	-2.7	4.2	-7.0	-1.0	6.0	-5.4	-1.2	4.2

Table 5: WRSF Runoff and Interflow as a Percentage of Annual Precipitation*

Month	Runoff	Interflow		
		0 – 50 years	50 – 100 years	100+ years
January	0 %	0 %	0 %	0 %
February	0 %	0 %	0 %	0 %
March	0.25 %	0 %	0 %	1.0 %
April	2.75 %	0.36 %	1.7 %	1.7 %
May	1.15 %	1.3 %	0.72 %	1.0 %
June	0.4 %	1.1 %	0.64 %	1.0 %
July	0.2 %	1.1 %	1.5 %	1.5 %
August	0.1 %	1.3 %	1.6 %	2.1 %
September	0.15 %	0.7 %	1.4 %	1.7 %
October	0 %	0.18 %	0.32 %	0.88 %
November	0 %	0 %	0 %	0.22 %
December	0 %	0 %	0 %	0 %
Annual	*5 %*	*6 %*	*8 %*	*11 %*

Source: OKC (Appendix A)
*If monthly air temperatures are below zero, that month's runoff/interflow will be delayed until the following month

4.0 RESULTS

The water balance and water quality models were run for sufficient duration to ensure they captured interflow breakthrough and subsequent stabilization of constituent concentrations:

- Average Climate Scenario: The model was run until 2168 using the assumptions presented in the water balance used for the Water Licence application under average climate conditions (i.e., the previous assumptions presented in Table 2); and
- RCP 8.5 Climate Scenario: The model was updated with the assumptions and inputs presented in Section 3 and run until 2300. This scenario represents the impact of both climate change and revised modelling assumptions for the site WRSFs (Table 2).

As per the discussion provided in Section 2.0, the results for the RCP 8.5 Climate Scenario should be considered to be a conservative representation of the impacts of projected climate change. As stated previously, conservatisms in the assessment will be investigated through monitoring and updates to the model, and adaptive management strategies have been developed to identify situations of concern and provide mitigation in a proactive manner.

4.1 Water Balance

The impacts of climate change are apparent during closure and post-closure. Increased predicted precipitation results in higher overall watershed runoff and faster pit filling. As shown in Figure 4, under the RCP 8.5 climate scenario, Whale Tail Lake (North Basin) would reach its post-closure elevation by 2039, three years earlier than under the previously modelled average climate scenario.

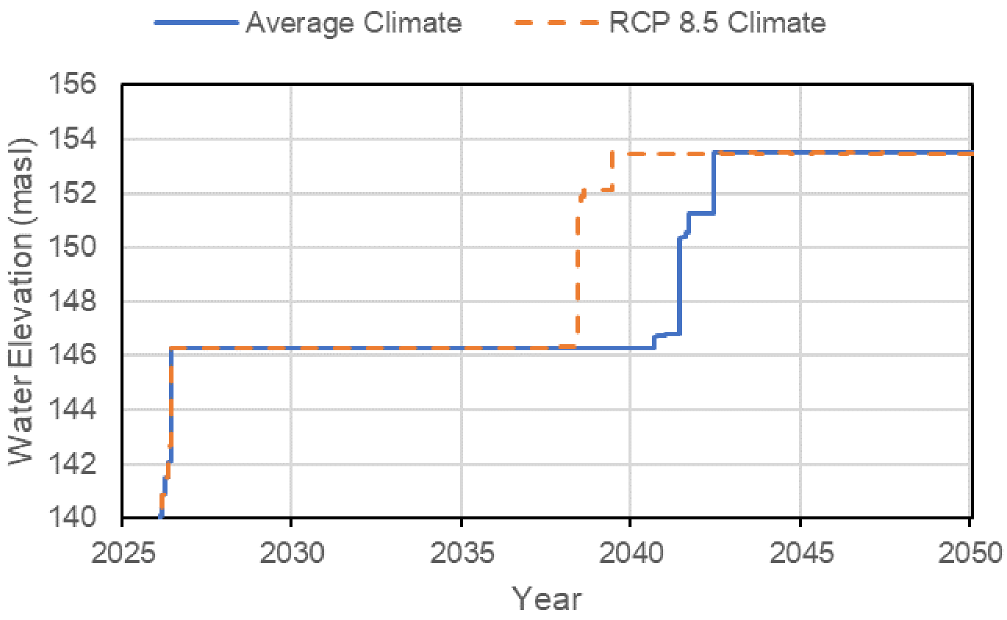

Figure 4: Predicted water levels in Whale Tail Lake (North Basin) under Average and RCP 8.5 Climate Scenarios

The most substantial impact of the updated inputs in the RCP 8.5 scenario on the water balance during closure/post-closure is predicted to be the volume of runoff and interflow from the WRSFs. The most substantial changes are caused by the following:

- The updated WRSF footprint used to calculate runoff and interflow have decreased by over 90%.
- By 2168, the annual precipitation is 50% higher under RCP 8.5 than under the average climate scenario.

Figure 5 and Figure 6 present the predicted cumulative runoff and interflow from the WRSFs under current average annual climate conditions and under the climate change scenario RCP 8.5. Under the RCP 8.5 climate scenario, the cumulative runoff from the WRSFs from the start of closure (2026) to 2168 is predicted to be 395,000 m^3 (approximately 90% lower than the previously predicted runoff of 4,571,000 m^3). As stated previously, this difference is primarily due to Okane's revised modelling assumptions for the site WRSFs as summarized in Table 2. By 2300, the cumulative runoff from the WRSFs under RCP 8.5 is 822,000 m^3.

Under average conditions scenario, little to no interflow was expected from the WRSFs until 2100. With the revised modelling assumptions for interflow under the RCP 8.5 climate scenario, interflow is assumed to occur in 2026. Despite this assumption, the interflow rate is predicted to be lower, resulting in cumulative flows of 1,441,000 m^3 by 2168 (approximately 60% lower than under the average climate scenario - 2,365,000 m^3). By 2300, the cumulative interflow from the WRSFs under RCP 8.5 is 3,344,000 m^3.

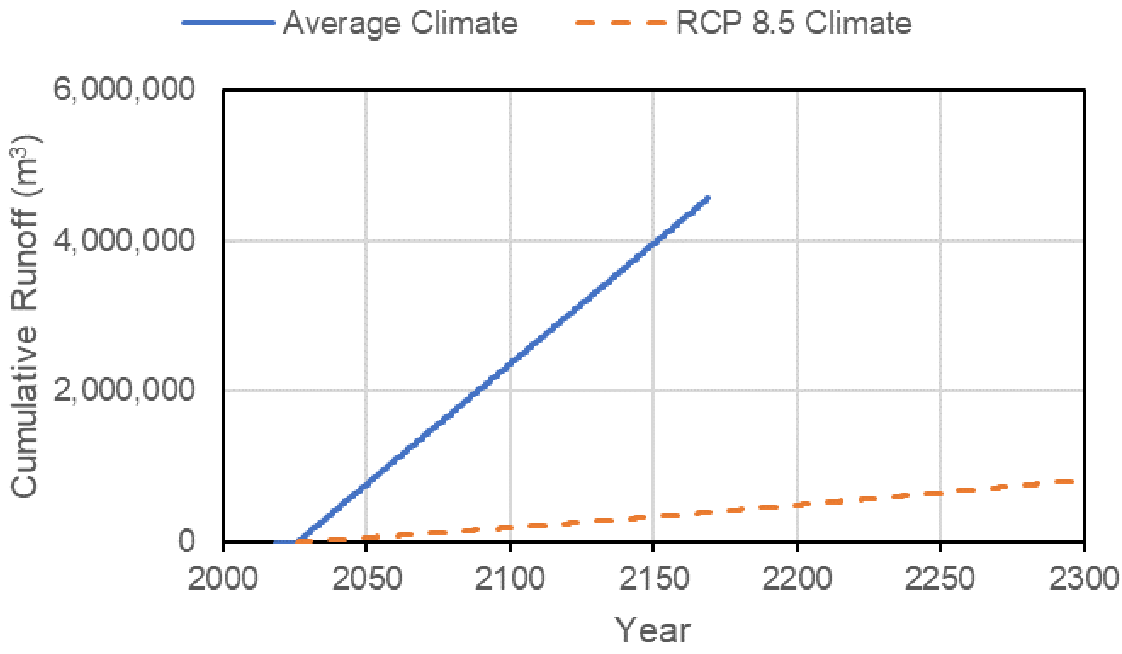

Figure 5: Cumulative Site Runoff from the WRSFs under Average and RCP 8.5 Climate Scenarios during Closure and Post-Closure

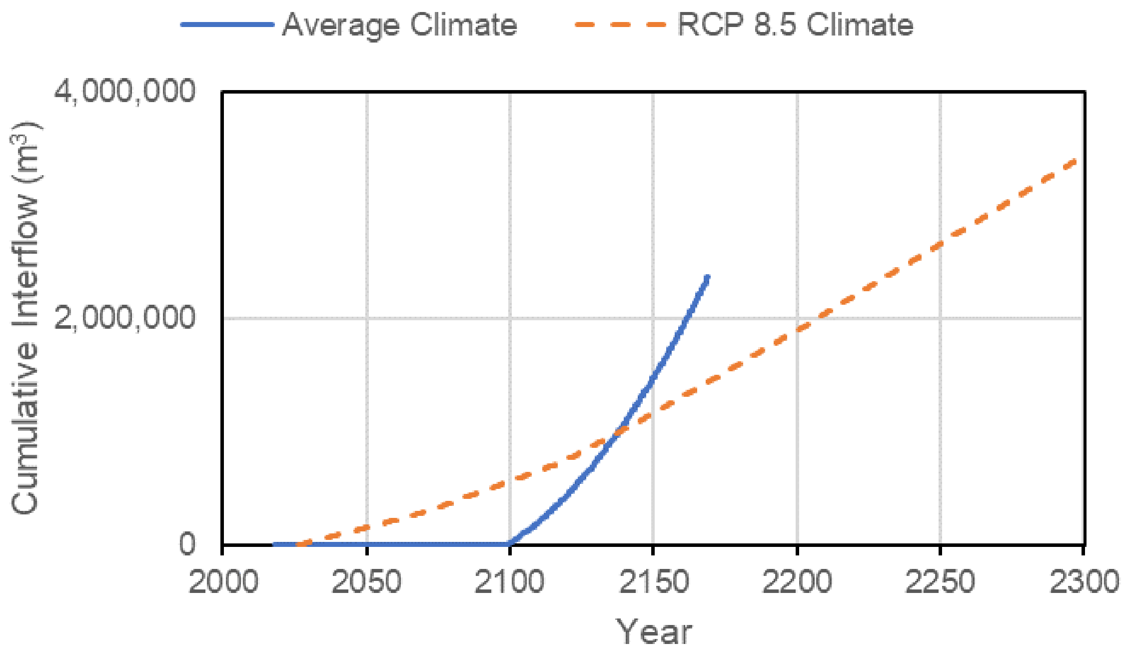

Figure 6: Cumulative Site Runoff from the WRSFs under Average Annual Climate Conditions and RCP 8.5 Climate Scenario

4.2 Water Quality

Results are presented in Figure 7 for total arsenic in Mammoth Lake for average climate conditions and the RCP 8.5 climate scenario. Total arsenic has been identified as a key Constituent of Potential Concern (CoPC), and all other modelled constituents show similar trends.

Due to updates in the area and associated mass of the WRSF providing loadings to runoff and interflow (see Table 2 for details regarding the calculation of this mass) under the RCP 8.5 climate scenario, concentrations in Mammoth Lake during operations are lower compared to those predicted for the average climate scenario. Back-flooding of the pits in closure is also earlier by three years, resulting in an earlier date for the reconnection of the flooded pit lake with Mammoth Lake.

Under the RCP 8.5 climate scenario, interflow leaving the WRSFs in closure accumulates mass from the cover material only, as the calculated pore space temperature below the cover material does not increase above 0°C; as a result, there is no contribution of mass loading from the waste rock below the cover. Loadings from the WRSF and, consequently, concentrations in Mammoth Lake, continue on a slight increasing trend as temperatures increase and drive a higher degree of oxidation of WRSF cover material; however, concentrations in Mammoth Lake reach steady state near the year 2250. at approximately 0.0078 mg/L.

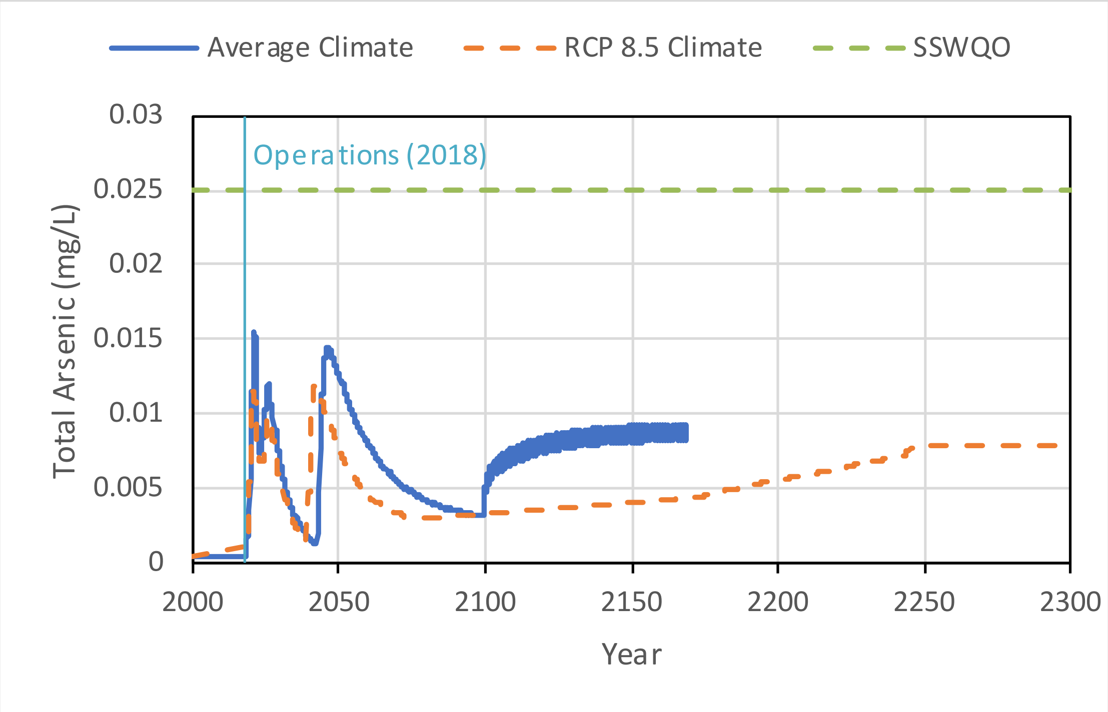

Figure 7: Total arsenic concentrations in Mammoth Lake for the average climate and RCP 8.5 scenarios

In summary, total arsenic concentrations in Mammoth Lake (Figure 7) for the average climate scenario are similar to the RCP 8.5 climate scenario throughout operations and closure; the RCP 8.5 climate scenario concentrations are slightly lower due to the updated assumptions of area contributing to the mass loadings to runoff from the WRSF. In post-closure, concentrations remain consistently lower than the average climate scenario (and the SSWQO).

5.0 CLOSURE

This technical memorandum was prepared and reviewed by the undersigned.

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https://golderassociates.sharepoint.com/sites/113014/project files/5 technical work/stage-2_tcs/01_working_responses/climate change assessment/rev0/19127573_430_tm_climatechangescenariorcp8.5-rev0.docx

REFERENCES

Bush E, Lemmen DS, editors. 2019. Canada's Changing Climate Report. Ottawa ON: Government of Canada. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR_FULLREPORT-EN-FINAL.pdf

Charron, I. 2016. A Guidebook on Climate Scenarios: Using Climate Information to Guide Adaptation Research and Decisions, 2016 Edition. Ouranos, 94p. Retrieved from https://www.ouranos.ca/publication-scientifique/Guidebook-2016.pdf

Climatedata.ca. 2019. Annual values for Baker Lake. Retrieved December 5, 2019 from https://climatedata.ca/explore/location/?loc=OABNP.

Golder (Golder Associates Ltd.). 2019a. Whale Tail Pit – Expansion Project. 2019 Mean Annual Water Balance Update. 18108905-294-RPT-Rev1. May 2019.

Golder. 2019b. Mine Site and Downstream Receiving Water Quality Predictions, Whale Tail Pit – Expansion Project. 18108905-308-RPT-Rev0. May 2019.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from http://www.ipcc.ch/report/ar5/wg1/

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J., van Vuuren, D. P. P. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change, 109(1), 213–241. http://doi.org/10.1007/s10584-011-0156-z

OKC (Okane Consultants Inc.). 2019a. Whale Tail Project – Thermal Modelling of the Whale Tail and IVR WRSFs. 23 July 2019.

OKC. 2019b. Landform Water Balance Modelling of Whale Tail and IVR WRSF rev 3. 10 May 2019.

Van Vuuren et al. 2011. The representative concentration pathways: an overview, Climatic Change (2011) 109:5–31, DOI 10.1007/s10584 011 0148 z.

SNC (SNC Lavalin Inc.). 2015. Whale Tail Pit Project. Permitting Level Engineering. Geotechnical and Water Management Infrastructure. 11 December 2015.

Zickfeld, K., Eby, M., Weaver, A. J., Alexander, K., Crespin, E., Edwards, N. R., Zhao, F. 2013. Long-Term climate change commitment and reversibility: An EMIC intercomparison. Journal of Climate, 26(16), 5782–5809. http://doi.org/10.1175/JCLI-D-12-00584.

APPENDIX A

Landform Water Balance Modelling of Whale Tail and IVR WRSF under RCP8.5

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Memorandum

To: Michel Groleau – Nunavut Permitting Lead, Agnico Eagle Mines Ltd.

From: Gillian Allen, Geoenvironmental Engineer

Cc: Etienne Parent – Agnico Eagle Mines Ltd.

Our ref: 948-011-015 rev4

Date: December 19, 2019

Re: **Agnico Eagle Mines Ltd - Landform Water Balance Modelling of Whale Tail and IVR WRSF under RCP8.5 rev4**

Okane Consultants Inc. (Okane) was retained by Agnico Eagle Mines Limited – Meadowbank Division (AEM), to complete an updated thermal assessment of the Whale Tail waste rock storage facility (WRSF) at the Amaruq property under the Representative Concentration Pathway 8.5 (RCP8.5) climate change scenario. Thermal modelling will assist in developing the expected seasonal active layer thickness under climate change conditions, as well as determine if permafrost conditions within the WRSFs are sustainable under climate change conditions. The ultimate objective of the project is to demonstrate the physical and chemical stability of the Whale Tail and IVR WRSFs while optimizing risk and cost for AEM.

As part of this objective, a landform water balance was completed, including estimates of runoff, interflow, and basal seepage rates for different slopes and aspects of the WRSF (if applicable) under the Representative Concentration Pathway 8.5 (RCP8.5) climate change condition. The following memorandum summarizes the results of the landform water balance. A separate detailed modelling report summarizes specific modelling background and methodology (Okane, 2019[1]).

Methodology

GeoStudio Version 10[2] was used to conduct the modelling for this project. This version of GeoStudio is a substantial upgrade to previous versions software as it is able to account for advective air flow as well as gas consumption due to mineral oxidation within the WRSF and associated heat generation via an add-in module developed for the software. Four components of the GeoStudio suite of programs were used in combination for this project: SEEP/W, TEMP/W, AIR/W, and CTRAN/W (with the gas consumption and exothermic reactions add-in incorporated into the CTRAN analysis).

Models representative of selected locations of thermistor strings at Meadowbank's Portage WRSF were simulated for the same period of time as the thermistor strings have been operational. The model results were then compared to the field data to determine that the model reasonably estimated field thermal conditions. Material inputs for the model were calibrated to provide a reasonable comparison to the field data. A detailed description of all material inputs can be found in the detailed thermal modelling report (Okane, 2019)[1].

Following the one-dimensional calibration described above, a two-dimensional (2-D) cross section was developed (Figure 4) to determine the main factors promoting and inhibiting freeze-back of and seepage (amount and timing) from the WRSFs. The existing 4.7 m cover system design was modelled as the base case. Models consider coupled gas, heat, water, and air transfer processes. Additionally, the models account for the exothermic oxidation of sulphide materials. Therefore, TEMP/W, SEEP/W, and AIR/W components of the GeoStudio software suite were used in combination with the Gas Consumption and Exothermic Reactions add-in module GEOSLOPE developed with Okane to simulate sulphide oxidation.

Climate Change

As part of the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), the IPCC adopted new representative concentration pathways (RCPs) to replace the previous emission scenarios of the Special Report on Emission Scenarios (SRES)[3]. The four scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) are named after the radiative target forcing level for 2100, which are based on the forcing of greenhouse gases and other agents and are relative to pre-industrial levels[4]. RCP6.0 represents a medium-high RCP with stabilization of radiative forcing shortly after 2100 through the use of technology and policy.

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[1] Okane Consultants Inc. 2019. Whale Tail Project – Thermal Modelling of the Whale Tail and IVR WRSFs. 948-011-R-009. May 2019.

[2] GEOSLOPE, 2019. GeoStudio 2019. Online. https://www.geoslope.com

[3] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

[4] Van Vuuren, D.P., Edmonds, J., Kainuma, M., Raihi, K., Thomson, A., Hibbard, K. Hurtt, G.C., Kram, T. Krey, V., Lamarque, J.F., et al. 2011. The representative concentration pathways: an overview. Climatic Change. Vol. 109.

RCP8.5 represents a high RCP with increasing emissions that do not stabilize until after 2100[4]. This RCP is typically used as a worst-case scenario where no climate policy is undertaken. The RCP8.5 results can be used as an extreme to estimate performance if the change in forcing is lower.

Temperature and precipitation at the Whale Tail Project are both expected to increase under the RCP8.5 climate change scenario, with temperatures expected to increase at a rate of approximately 0.12°C/year. Precipitation increases approximately 0.7 mm/year (100 mm total increase over 150 years) for RCP8.5. Figure 1 and Figure 2 show the annual temperature and precipitation, respectively, estimated for the RCP8.5 150-year climate database developed for the Whale Tail Project. Results from the period indicated by the black dashed lines (2093-2118) are shown below.

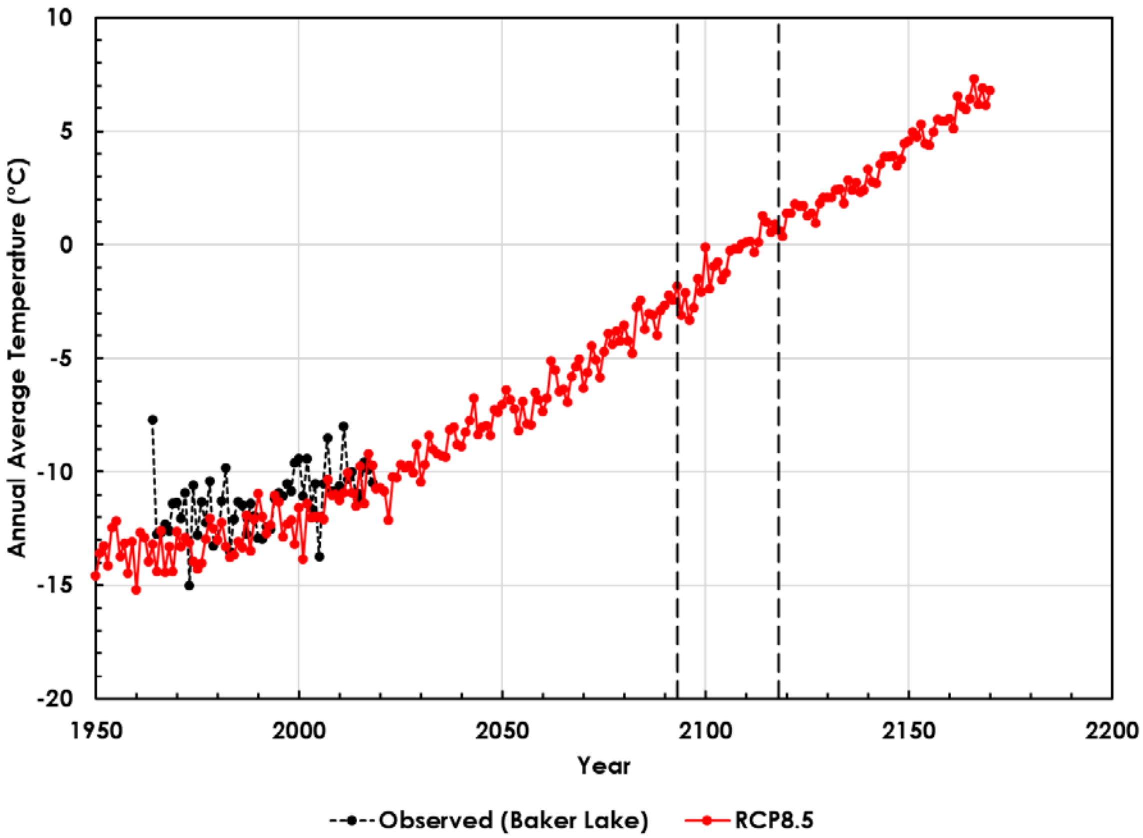

Figure 1: Annual average temperature estimated for the RCP8.5 climate change scenario. Observed temperature at Baker Lake is also shown.

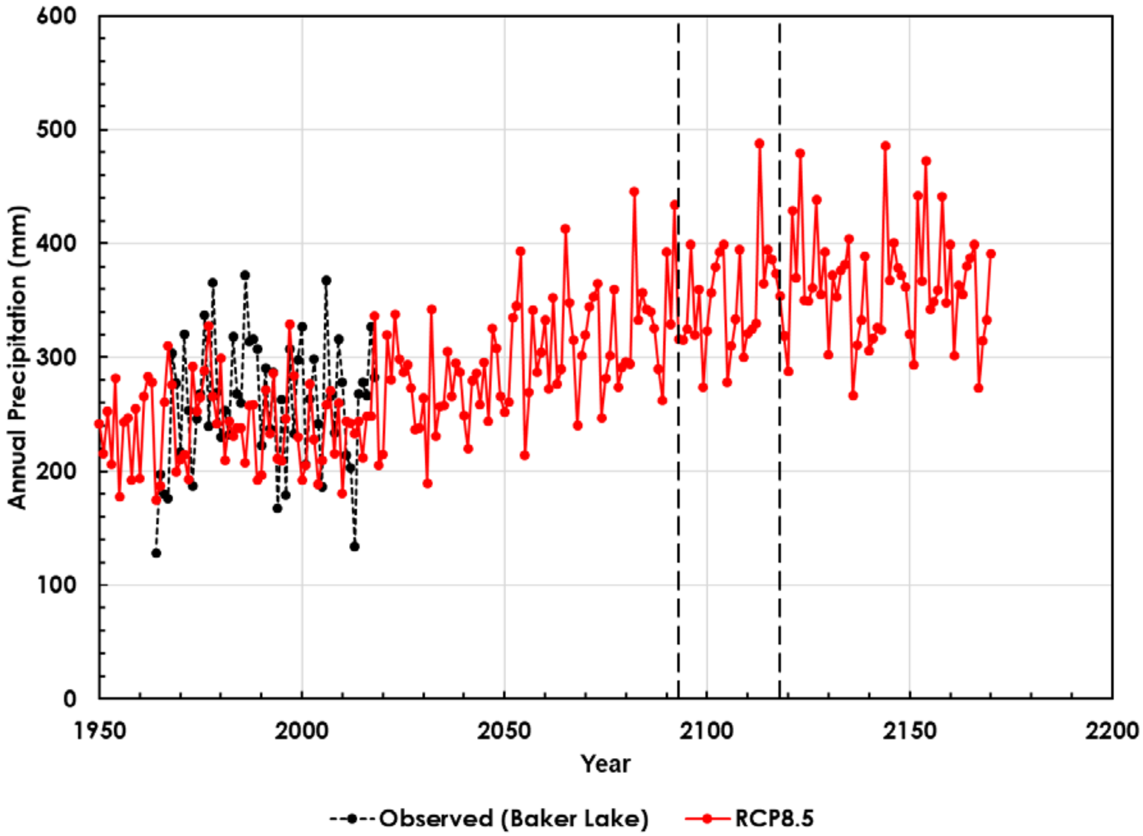

Figure 2: **Annual precipitation estimated for the RCP8.5 climate change scenario. Observed precipitation at Baker Lake is also shown.**

Model Inputs

Daily inputs of maximum and minimum air temperature; maximum and minimum relative humidity (RH); average wind speed; daily net radiation; and precipitation (amount and duration) are required for modelling. The climate change database was developed following the recommendations outlined on the Canadian Climate Data and Scenarios (CCDS) website, which is wholly supported by Environment and Climate Change Canada (ECCC)[5]. The second-generation Canadian Earth System Model (CanESM2), developed by the Canadian Centre for Climate Modelling and Analysis (CCCma), was used as the predictor global circulation model (GCM) to downscale and make climate change databases representative of the Whale Tail Project. Statistically downscaled daily temperature and precipitation under RCP8.5 from the Pacific Climate Impact Consortium[6] were used to develop the RCP8.5 climate change database. The other climate variables (i.e. relative humidity and net radiation) were downscaled using the Statistical Downscaling

[5] Canadian Climate Data and Scenarios (CCDS). 2018. Online. http://climate-scenarios.canada.ca/

[6] Pacific Climate Impacts Consortium (PCIC). 2018. Online. https://pacificclimate.org/

Model (SDSM)[7,8,9], with the exception of wind speed due to the lack of climate change predictors. Current CCCma CanESM2 model runs are limited temporally to 2100. Predictions beyond 2100 for the modelling program are based upon general trends and can therefore be considered to include much greater uncertainty. Results shown in this memo are based around 2100 to reflect this uncertainty in predictions beyond 2100. Refer to Appendix A of Okane (2019)[1] for a detailed description of the climate database basis and development.

Numerical modelling under RCP8.5 was completed for the NW-SE Whale Tail cross section labelled ‘A’ in Figure 3 and shown in Figure 4, as it is expected to have the most diverse range in behaviour due to the potential for advective cooling in the predominant wind direction.

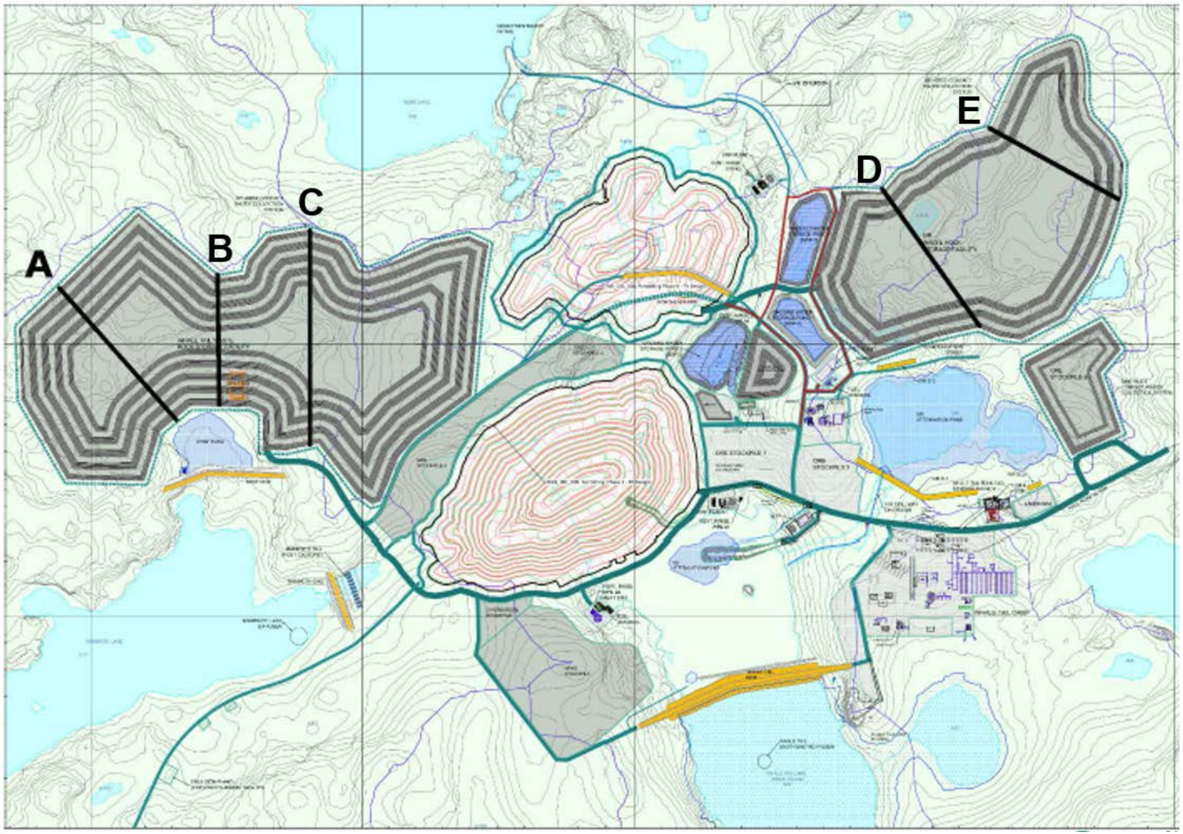

Figure 3: Location of cross-sections of Whale Tail and IVR WRSFs.

[7] Wilby, R.L., Dawson, C.W. Murphy, C. O’Conner, P., and Hawkins, E. 2014. The Statistical DownScaling Model – Decision Centric (SDSM-DC): Conceptual basis and applications. Climate Research, 61, 251-268.

[8] Wilby, R.L. and Dawson, C.W. 2013. The Statistical DownScaling Model (SDSM): Insights from one decade of application. International Journal of Climatology, 33, 1707-1719.

[9] Wiby, R.L., Dawson, C.W. and Barrow, E.M. 2002. SDSM – a decision support tool for the assessment of regional climate change impacts. Environmental and Modelling Software, 17, 145-157.

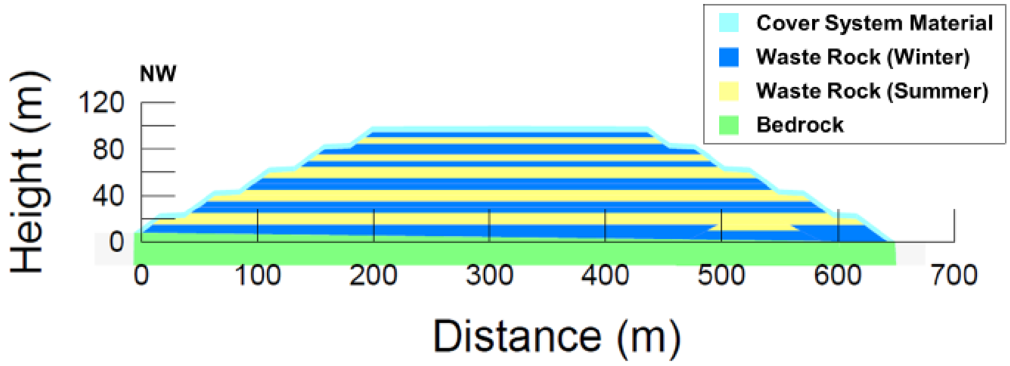

Figure 4: **Northwest-Southeast cross-section through Whale Tail WRSF at closure (A).**

Results

Effective Precipitation

Effective precipitation is the annual distribution of total rainfall and snowmelt as calculated by the GeoStudio model. Effective precipitation is a function of air temperature and total precipitation; where air temperature is used to determine whether precipitation falls as snow or rain. When temperature is above 0°C, incident precipitation occurs as rain; when temperature is below 0°C, incident precipitation occurs as snow. Effective precipitation also accounts for losses due to sublimation from the snowpack calculated within the model; therefore, snowmelt is the portion snowfall interacting with the landform. Therefore, effective precipitation can be defined as the rainfall plus snowmelt.

$$Effective\ Precipitation = Rainfall + Snowmelt$$

Effective precipitation was determined for the 150-year climate database, to be used in further modelling. Monthly trends for this time period indicate increasing effective precipitation trends from April through November (Figure 5).

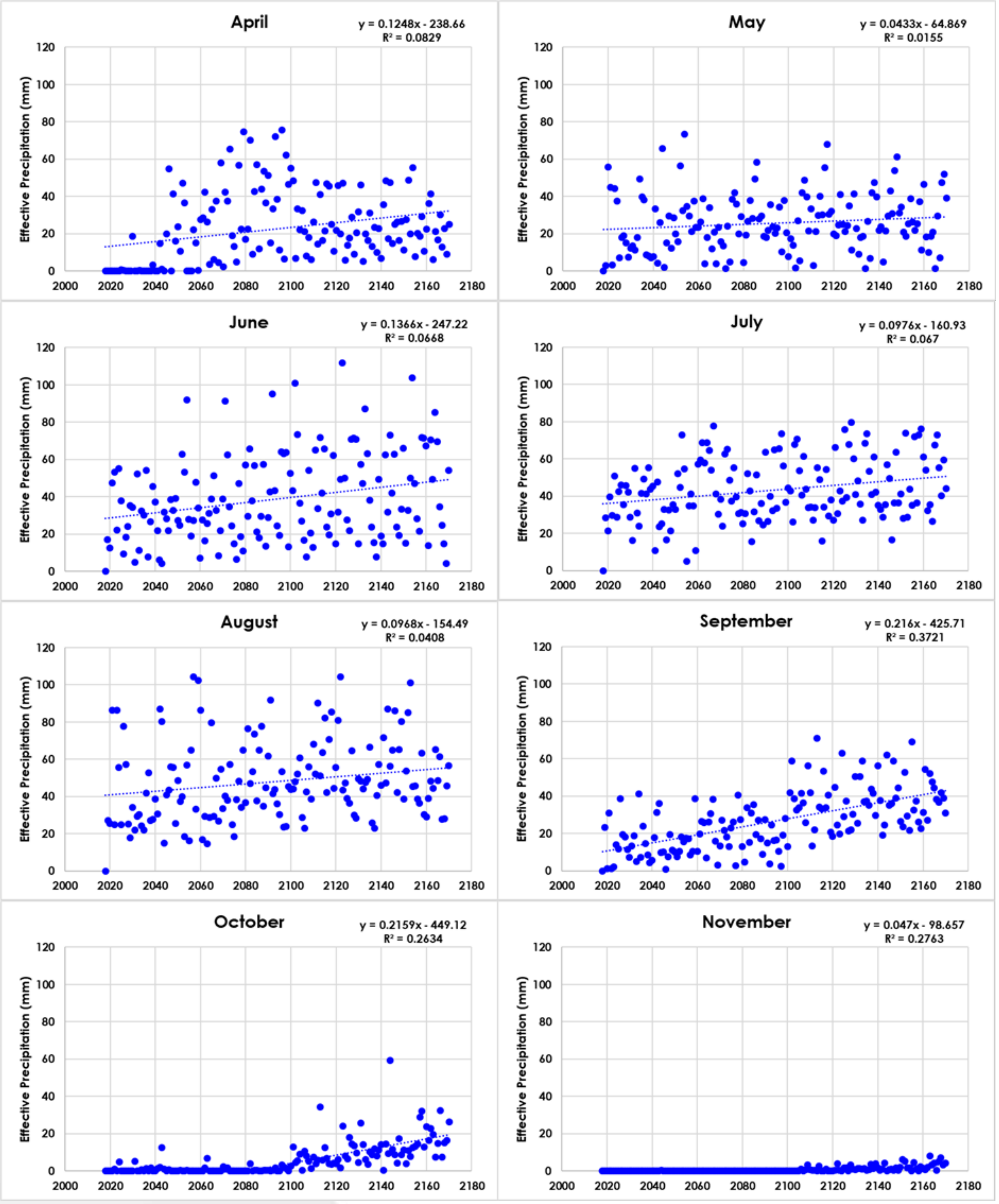

Figure 5: Monthly effective precipitation based on the results of the GeoStudio water balance modelling for the 150-year climate database.

Surface Water Balance

A summary of the surface water balance for the Amaruq WRSFs is provided in Table 1 for the current modelling, as well as previous modelling effort under RCP 6.0. Results of the surface water balance support the conceptual model that the hydraulic regimes are expected to be different based on the North and South aspect. Generally, higher net radiation results in greater evaporation and soil heating. With more evaporation, less water is available to runoff and/or infiltrate. Higher net radiation will also result in more sublimation, as more energy is available to convert snow into water vapour.

Table 1: Summary of average surface water balance for different aspects of the WRSF under RCP 8.5 and RCP 6.0.

Water Balance Parameters	Plateau		SE Aspect		NW Aspect	
	RCP 8.5	RCP 6.0	RCP 8.5	RCP 6.0	RCP 8.5	RCP 6.0
Total Precipitation (mm)	329 mm	296 mm	329 mm	296 mm	329 mm	296 mm
Rainfall (% of Total Precipitation)	60-65%	55-60%	60-65%	55-60%	60-65%	55-60%
Snow (% of Total Precipitation)	35-40%	40-45%	35-40%	40-45%	35-40%	40-45%
Actual Evaporation (% of Total Precipitation)	50-55%	25-30%	50-55%	30-35%	45-50%	25-30%
Runoff (% of Total Precipitation)	<5%	<5%	<5%	<5%	5-10%	10-15%
Net Percolation (% of Total Precipitation)	10-15%	30-35%	5-10%	25-30%	5-10%	20-25%
Sublimation (% of Total Precipitation)	30-35%	35-40%	35-40%	40-45%	30-35%	40-45%

In order to simplify runoff outputs from the surface water balance, the runoff values for each aspect were weighted based on the relative area represented by each aspect. This results in an overall runoff rates from the Whale Tail and IVR WRSFs of approximately 5% of incident precipitation. Runoff was assumed to interact with surficial materials to a depth of 30 cm.

The surficial materials interacting with landform runoff will change over time as progressive reclamation is completed. Table 2 and Table 3 summarize the relative percentage of runoff expected to interact directly with the cover system material and waste rock material over time. These percentages are not expected to change under RCP8.5, as they are based on construction schedules.

Table 2: Relative amount of runoff from bare waste rock vs cover system materials at the Whale Tail WRSF.

Year	Percentage of Runoff from Bare Waste Rock	Percentage of Runoff from Cover System
2019	100%	0%
2020	0%	100%

Table 3: Relative amount of runoff from bare waste rock vs. cover system materials at the IVR WRSF.

Year	Percentage of Runoff from Bare Waste Rock	Percentage of Runoff from Cover System
2021	100%	0%
2022	0%	100%

The majority of runoff from the WRSFs is expected to occur as a result of spring melt, however some runoff is expected throughout the unfrozen period. The distribution of runoff by month is provided in Table 4.

Table 4: Runoff distribution by month for the Whale Tail and IVR WRSFs.

Month	Percent of Total Annual Runoff by Month (%)	
	RCP 8.5	RCP 6.0
January	0%	0%
February	0%	0%
March	<5%	0%
April	55-60%	0%
May	20-25%	0%
June	5-10%	85-90%
July	<5%	5-10%
August	<5%	5-10%
September	<5%	<5%
October	0%	0%
November	0%	0%
December	0%	0%

As the benches and plateaus will be constructed with a safety berm and back sloped towards the landform (Figure 6), runoff is only expected on the lowest slope of the WRSF (Slope 5 - Figure 7).

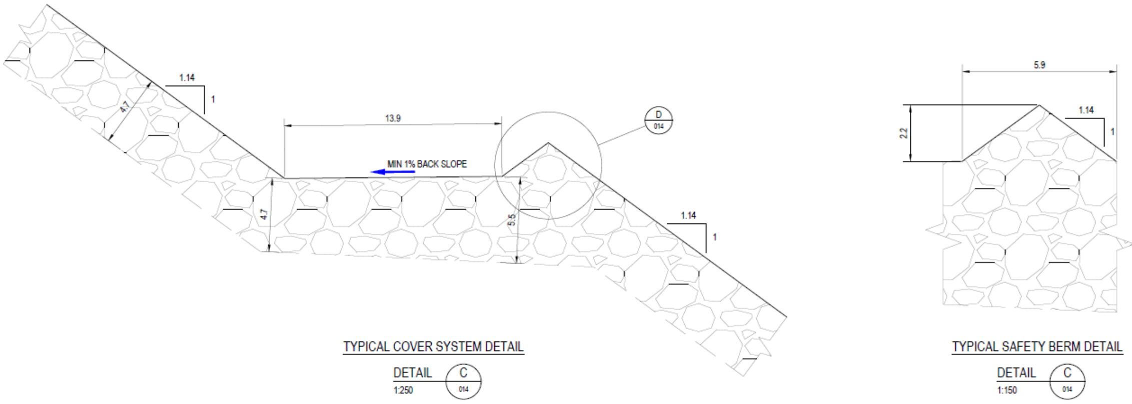

Figure 6: Typical cover system design with back sloping and safety berm.

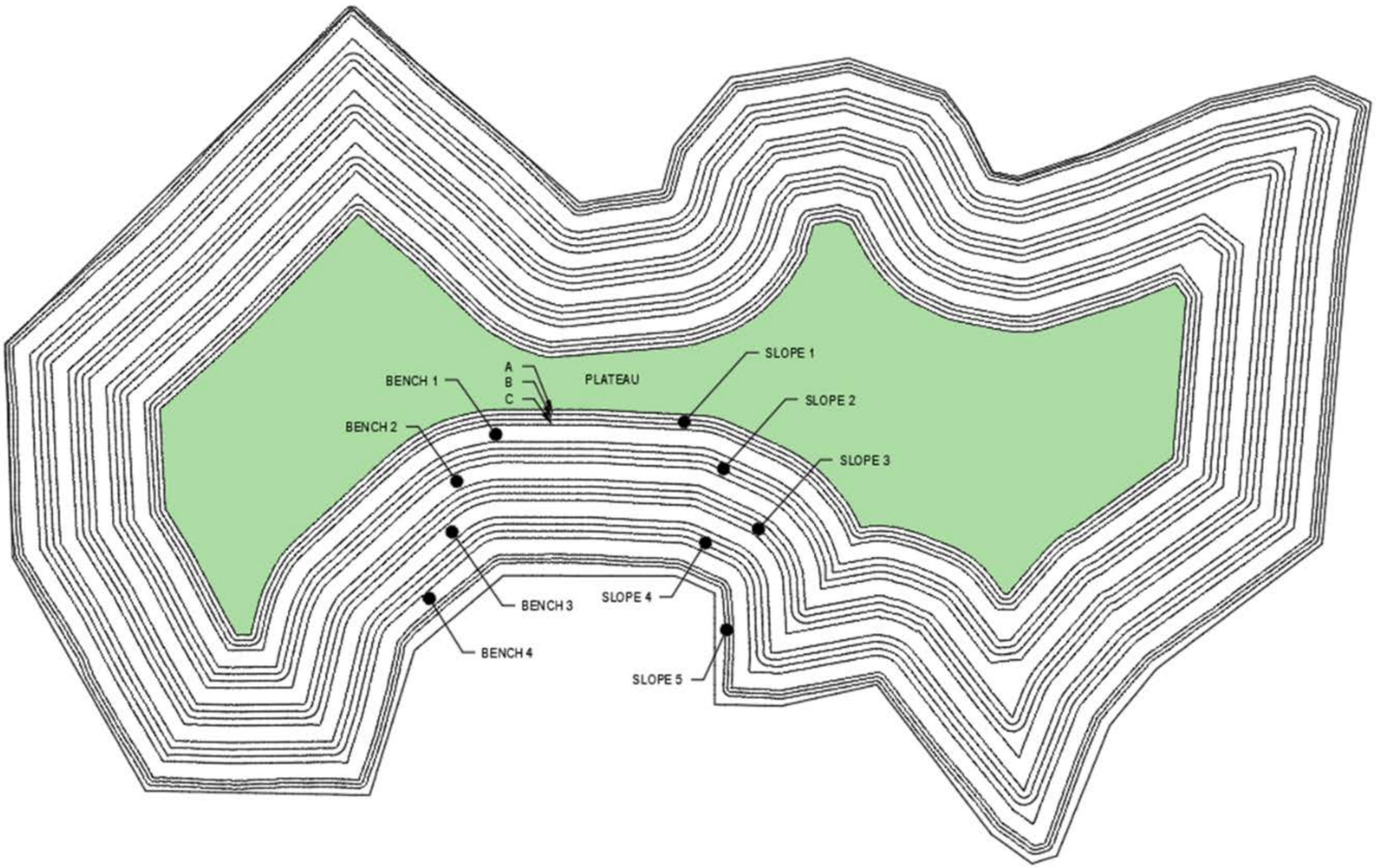

Figure 7: Sketch of Whale Tail WRSF and areas delineated for water balance assessment.

Basal Seepage

The high infiltration capacity of the cover system materials and waste rock materials result in a propensity for incident precipitation to result in infiltration, rather than runoff (Table 1). As water infiltrates into the surficial materials, net percolation flows vertically through the WRSF, eventually freezing back at depth. The base layer of the WRSF is consistently frozen from the time of placement. As a result, basal seepage from the landform is negligible.

Interflow

There is some lateral flow of water within the cover system on the angle of repose slopes (known as interflow). Interflow occurs when infiltration occurs along the lowest slope and bench of the WRSF. This flow path interacts with the entire 4.7 m depth of the cover system, along a maximum flow path of approximately 20 m (Figure 8). Interflow has the potential to interact with the underlying waste rock within the first bench when infiltration occurring along the bench infiltrates vertically prior to being diverted by low conductivity ice lenses.

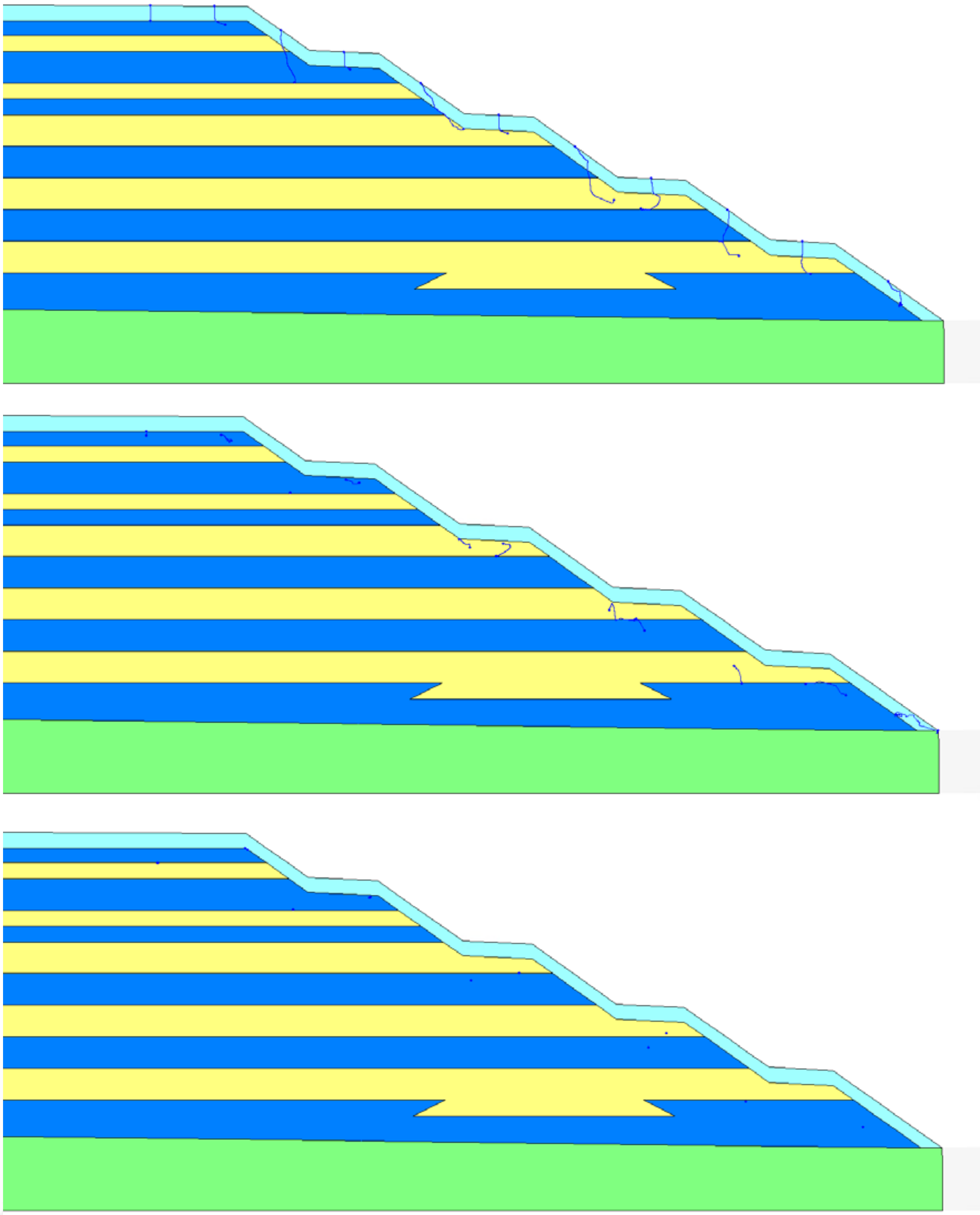

Figure 8: Sketch of interflow flow paths of the Whale Tail WRSF near surface with tracked particles (blue) shown for modelled periods 2093-2098 (top), 2098-2103 (middle), and 2108-2113 (bottom).

The percentage of incident precipitation reporting as interflow changes over the 150-year modelled period. Interflow is strongly influenced by the coarser-textured nature of the cover material. The coarse texture allows for a high surface infiltration capacity; hence, runoff is relatively low. In addition, the underlying PAG waste rock is not frozen initially and surface infiltration reports as net percolation, wetting up the waste rock material. The result is less interflow initially (Table 5) under RCP8.5 precipitation regime. Interflow interacts with both the cover system material and with a small portion of the underlying waste rock. Annual timing of interflow also changes over the time period modelled under the RCP 8.5 temperature regime (Table 6).

Table 5: Interflow distribution by month of the Whale Tail WRSF as a function of the incident precipitation landing on the lowest slope and bench of the WRSF.

Month	Percent of Incident Precipitation on Slope 5 and Bench 4 Reporting as Interflow (%)		
	0 – 50 Years	50 – 100 Years	100 – 150 Years
Non-Contact	3%	5%	8%
Contact	3%	3%	3%
Total	6%	8%	11%

Table 6: Interflow distribution by month of the Whale Tail WRSF as a function of total interflow.

Month	Percent of Interflow Occurring by Month		
	0 – 50 Years	50 – 100 Years	100 – 150 Years
January	0%	0%	0%
February	0%	0%	0%
March	0%	1%	9%
April	6%	21%	15%
May	21%	9%	9%
June	18%	8%	9%
July	19%	19%	14%
August	21%	20%	19%
September	12%	18%	15%
October	3%	4%	8%
November	0%	0%	2%
December	0%	0%	0%

Once the WRSF has reached full capacity, water that would have previously infiltrated beyond the cover system may be redirected as either interflow within the cover system or runoff due to the ice layer below the active zone. It should be noted that the WRSF did not reach full capacity during the 150-year model run. Put simply, during the 150-year modelled period, interflow between benches did not increase appreciably, despite the presence of low permeability ice layers near surface. Modelled water movement indicates that it is likely that only a small portion of overall net percolation resulting in interflow will exit the landform in the long-term.

Pore Space Temperature

Differences in the pore space temperature relative to ambient air impacts the ability to scale chemical loading within the Amaruq WRSFs. Averages of monthly temperature based on the RCP8.5 climate change scenario were taken across a vertical profile through the thermal cover at Slope 5 along the southeast aspect of Section A (Figure 3), representing the most conservative scenario given increased soil temperature and net radiation.

Pore space temperature profiles along Slope 5 were determined for depths of 0.0 to 1.5 m (Figure 9), 1.5 to 3.0 m (Figure 10), and 3.0 to 4.5 m (Figure 11) below the surface of the cover system. Forecasting of trends in pore space temperature were projected to 2250 using an asymptotic regression, as temperatures are expected to reach equilibrium as air temperatures reach a steady-state.

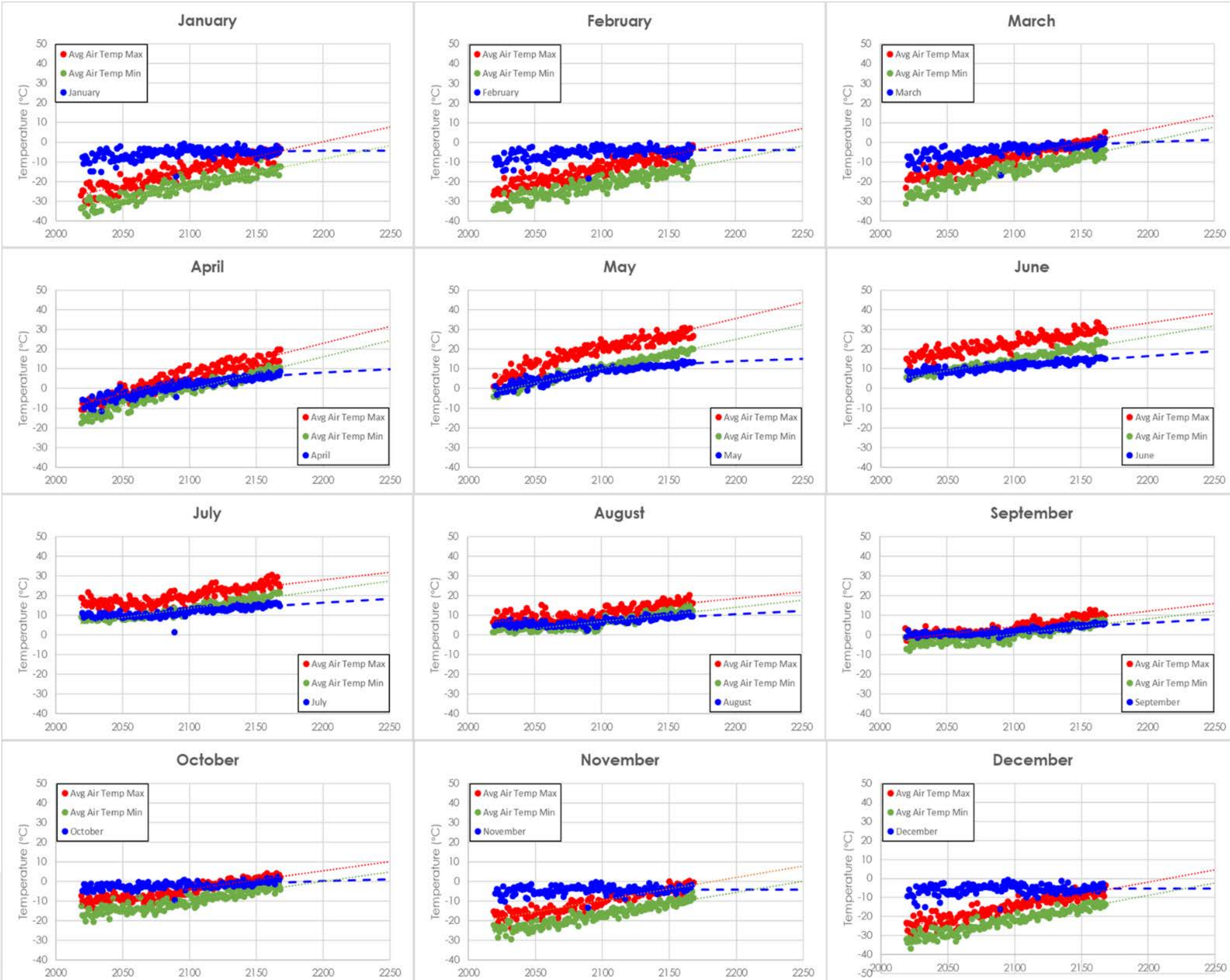

Figure 9: Temperature profile along Slope 5 from 0 to 1.5 m below the top of cover compared to projected ambient air temperature.

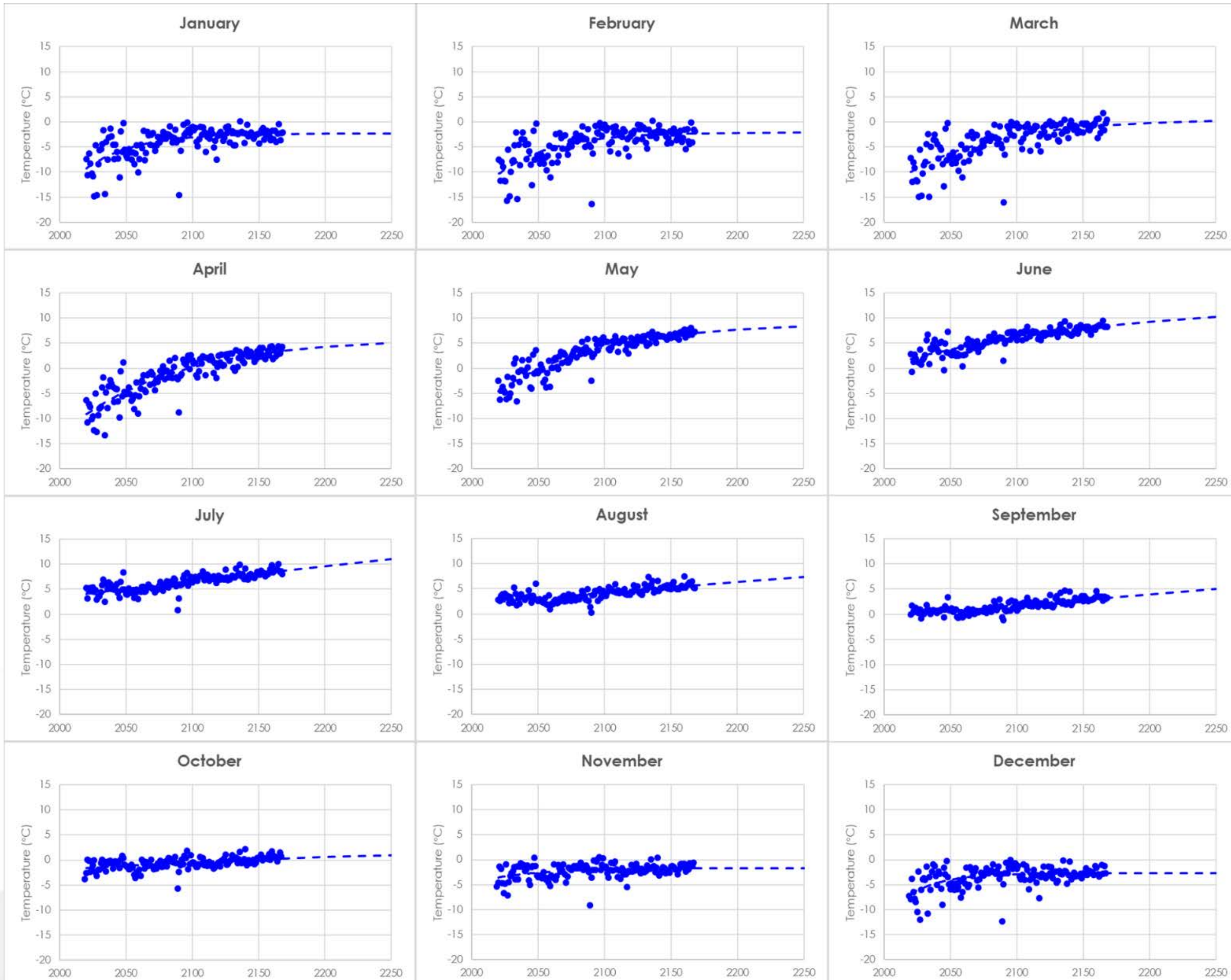

Figure 10: Temperature profile along Slope 5 from 1.5 to 3.0 m below the top of cover.

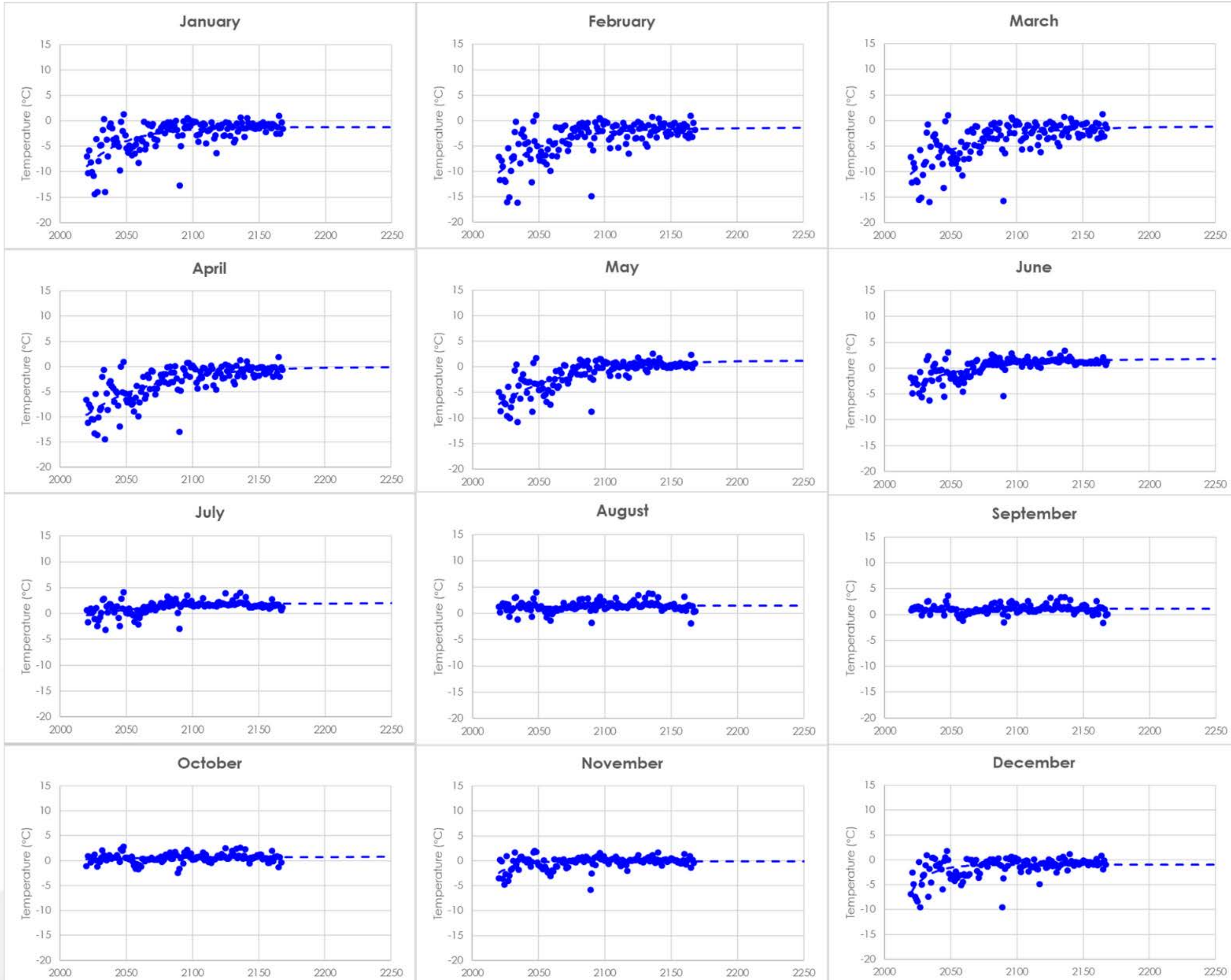

Figure 11: **Temperature profile along Slope 5 from 3.0 to 4.5 m below the top of cover.**

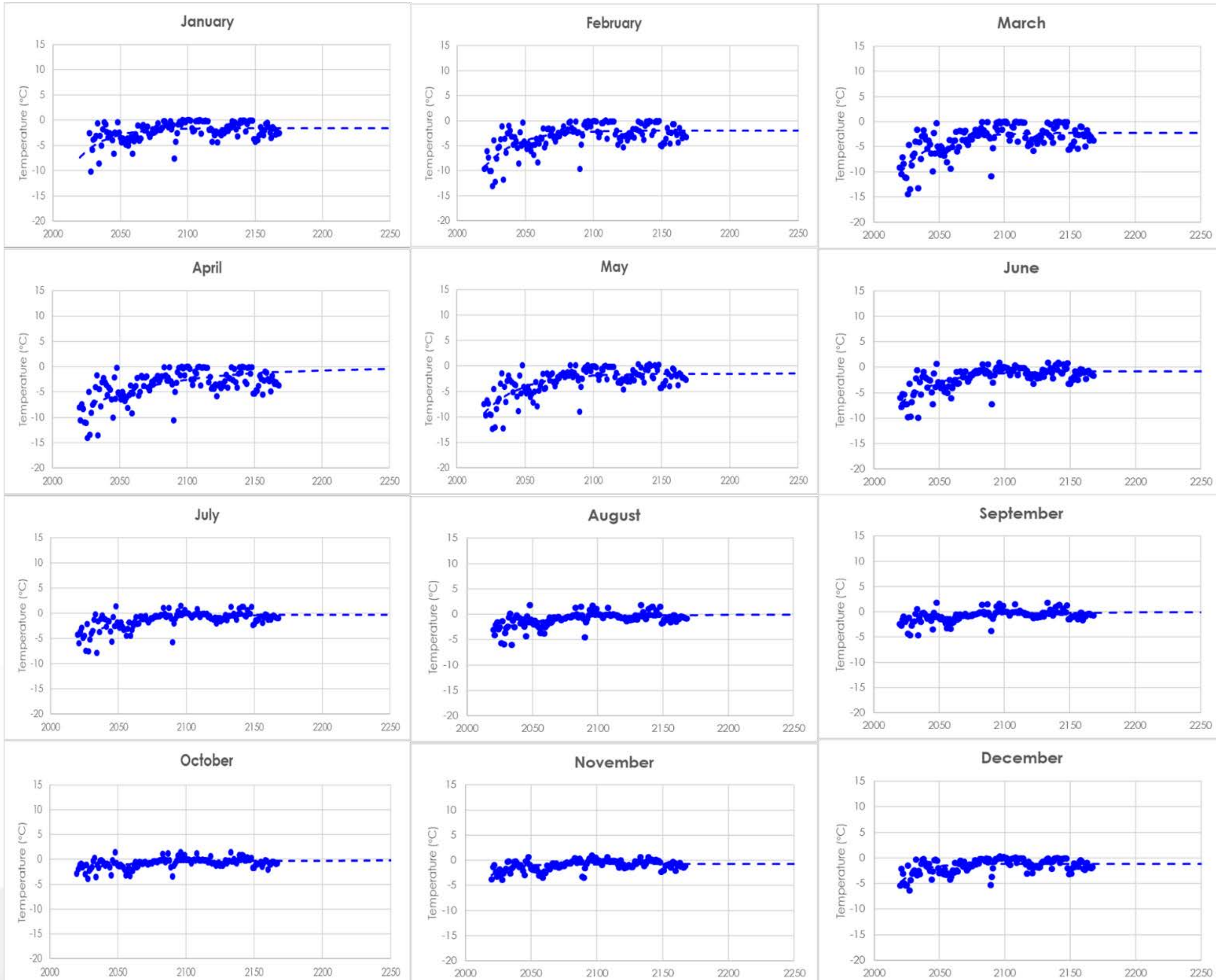

Figure 12: Temperature profile along Slope 5 below the cover system (4.7 to 9 m depth).

Closure

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at 306-713-1568 or gallen@okc-sk.com should you have any questions or comments.